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FEM ANLAYSIS OF MICROWAVE HYPERTHERMIA AND THE EFFECT OF SAR &TEMPERATURE ELEVATION ON LIVER TUMOR

SAJAN SINGH[1], SATBIR SINGH SEHGAL[2]& HARJOT SINGH GILL[3]

[1]*Research Scholar, Mechanical Engineering Department, Chandigarh University, Gharuan, Mohali, Punjab, India*

[2]*Professor, Mechanical Engineering Department, Chandigarh University, Gharuan, Mohali, Punjab, India*

[3]*Assistant Professor, Mechanical Engineering Department, Chandigarh University, Gharuan, Mohali, Punjab, India*

ABSTRACT

Radio-Frequency therapy is a common treatment in the cancer therapy. The goal of this paper is to study the effect of electromagnetic waves on the liver cancer tissue. This liver model will allow us to examine the effect of temperature raise, temperature profile and Specific Absorption Ratio. In Microwave hyperthermia therapy, soft tissues are targeted for the short duration of time, which is responsible for the coagulation of cancerous cells. In this review, the microwave coaxial antenna operating at the frequency of 2.4GHz by varying the opening size of the antenna for the removal of the tumor.3D CAD model of liver and cancerous tumor was used for the FEM analysis. RF wave used in the FEM analysis are of frequencies of 2.4GHz respectively. Analysis was done by using the COMSOL-Multiphysics.

KEYWORDS: Antenna, FEM Model, Microwave Coagulation Therapy, SAR & Coaxial Antenna

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Original Article

INTRODUCTION

In the current years, the gain of microwave has drawn attention of the researchers. The advantage of microwave coagulation and microwave hyperthermia for medical treatments of cancer has been studied widely [1]. Treatment of cancer has been broadly studied, the use of coaxial antenna, which is thin microwave antenna used for the interstitial microwave coagulation therapy [2]. The heat produced in the existence of the time-variable, electric field is calculated by the value of its electric-conductivity, its electric properties and the dielectric permittivity and by some other properties [3]. The quantity which relates the heat generated in a tissue is known as Specific Absorption Rate (SAR):

$$SAR = \sigma\frac{E\hat{}2}{\rho}$$

(E) is the root mean square value of the time-harmonic &electric-field strength inside the tissue and ρ represents the mass density of the tissue. In SAR (Specific Absorption Rate), distribution for all cases are considered and compared, which is then used to calculate the heating patterns of the antennas. While in designing the antenna for microwave ablation, many scholars have started the use of mathematical models engrained in the computational electromagnetic analysis. While in the FEM analysis of microwave hyperthermia treatment, the computer modelling techniques are helpful. In the analysis of complex, particularly perfusion rate, which make FEM analysis an ideal choice over other solutions, which require many interpretation assumptions [4]. The work presented in this paper is based upon the electro-magnetic numerical analysis approach of FEM, because of its specific wise estimate to solve the bio-heat transfer equation. FEM model can provide precise solution for the

multiple systems of different equations, and they are well matched to heat transfer problems like ablation. In Hyperthermia (RF therapy), heating of the cancerous tumour is done under controlled conditions. Since, healthy tissue can absorb energy causing damage with the application of microwave, laser and ultrasound. The main purpose is to introduce the tissue damage, which is the function of the time-temperature, in which; the accurate prediction of the temperature in tissue is required. In the ablation process, the temperature profile depends upon the collaboration of microwaves with heat transfer in tissue and the tissue [5].

In the collaboration of microwave radiation with the tissue, circulation and of the Microwave radiations in tissue is administered by the Maxwell's equation:

$$\nabla * D = \rho_{free} \quad (1)$$

$$\nabla * b = 0 \quad (2)$$

$$\nabla * E = - \frac{\partial b}{\partial T} \quad (3)$$

$$\nabla * H = J + \frac{\partial D}{\partial T} \quad (4)$$

Maxwell equation can be used to solve the electromagnetic radiation in each tissue, and with the information of tissue, the electromagnetic properties such as relative-permittivity, conductivity, initial conditions and boundary conditions, model is accurate for the ablation process.

The temperature distribution in the cancerous tissue during an ablation process is obtained by solving a bio-heat equation [6]. The equation used for the modelling thermal-therapy measures is the Penne's bio-heat equation [7].

$$\rho C_P \frac{dT}{dt} + \nabla (-k\nabla T) = \rho_B C_B \omega_B (T_B - T) + Q_O + Q_E \quad (5)$$

Where,

ρ_B = Blood density (kg/m^3)

k = Tissue thermal conductivity (W/m*K)

C_B = Blood specific heat capacity

ω_B= Blood perfusion rate (1/s)

T_B = Arterial blood temperature (K)

$Q_{O=}$ Metabolism heat source (W/m^3)

Q_E = External heat source (W/m^3)

The initial temperature T_b is applied to all domains.

Penne's bio-heat equation does not consider the heat losses due to blood flow through the large vessels [8]. The model under consideration is liver, which is a highly-perfused organ, which has large blood vessels. Ablations are performed in closeness to these vessels, and are vulnerable to the heat sink effects. The heat, which is transferred due to blood flow in the large vessels near tumour region, must be considered during the preparation of treatment of the infected region.

FUNDAMENTAL ASPECTS OF BIO HEAT

The human body has a core temperature near 37ºC over a wide range of environmental conditions and during thermal stress, exposure can be maintained. The amount of blood flow on the body varies over a wide range, depending upon the need for its function. As the function of the heat transfer, blood is known for its dual influence on the thermal-energy balance. It can be sink or source, depending on the tissue local temperature. Blood perfusion rate represents the nutrient need in the tissue area. High blood perfusion is related with the heat dissipation during exercise or thermal stress. The properties of biological tissue are fundamental to understand the heat-transfer process in the biological system. Tissue temperature rise can be determined during RF waves, by solving bio-heat transfer equation, which considers the contribution of heat conduction, blood perfusion and external heating.

MAGNETIC AND ELCTRIC FIELD INTERACTION WITH LIVING TISSUE

How electric (E) and magnetic (H) field affect the human body is important aspect in bio-electromagnetics. Both E and H were defined to account for forces among charges. The fundamental interaction of E and H with materials is that, they exert forces on the charges in the materials [9].

Biological materials are usually lossy, and this loss changes the way the wave interacts with the material and its behaviour. A material has conductivity more than zero is lossy material. Dissipation of power in the lossy-material as a wave passes through it, hence producing loss to the spreading wave. Material will heat up as power dissipates in the material, and this is what raises the concerns of RF waves effect on human tissue [10].

In many electromagnetic field interactions, energy- transfer is of prime consideration. In hyperthermia for cancer therapy, the electric field is transformed in the whole body into the heat, which is the outcome of the therapy. The electric field can transfer energy to electric charges through the force it exerts on them, but magnetic field does not transmit energy to charge. Magnetic effect is not prominent in electromechanical biological interaction. The electric-power density in steady state is given by:

$$P = \sigma \frac{E^2}{2} (W/m^3)$$

Other techniques used are such as RF therapy and chemo-therapy that cause the cellular damage. All these are ablative techniques. In these treatments, the tissue temperature is raised in order to kill the malignant tissue. These types of treatments have a lot of potential, since it can offer a non-invasive treatment with low side effects [8]. In hyperthermia, temperature is raised above 42-43°C for the sufficient period of time. The challenge in achieving the temperature with non-invasive electromagnetic hyperthermia treatment is to focus electromagnetic (EM) power in the cancerous tissue while avoiding the normal tissue. In microwave frequency, energy couples in to the tissue through antennas that emits the microwaves [11]. The issue while working with the radio-therapy is to avoid heating the normal tissue, while we are heating the tumour. While the high conductivity of cancerous tumour tissue increases heating potential, and therefore, the high temperature difference can be attained. The spots in the healthy tissue areas results in unwanted side effects such as burns, blisters and extra pain. Most flexible approach focusing the EM energy is the use of the phase array system [12].A 2D FEM analysis for the treatment of the pathological tissues containing the tumors is presented. The analysis compares the model of co-axial antenna with one, two or three air slots. Model is based on TM mode coupled with Penne's equation under a transient state condition. The frequency of antenna used is 2.45GHz [13].

STRUCTURE OF ANTENNA

The antenna contains of a coaxial cable with a slot measuring 0.1 mm. The antenna is surrounded by a catheter, which is made of (polytetrafluoroethylene). Antenna operates at the frequency of 2.45GHz, the frequency which is used in for the coagulation therapy.

Table 1: Dimension of Coaxial Antenna

PROPERTIES	VALUE
Diameter of Teflon	2.58 mm
Diameter of the dielectric	1.68mm
Inner diameter of the conductor	0.51mm
Outer diameter of the conductor	2.2 mm

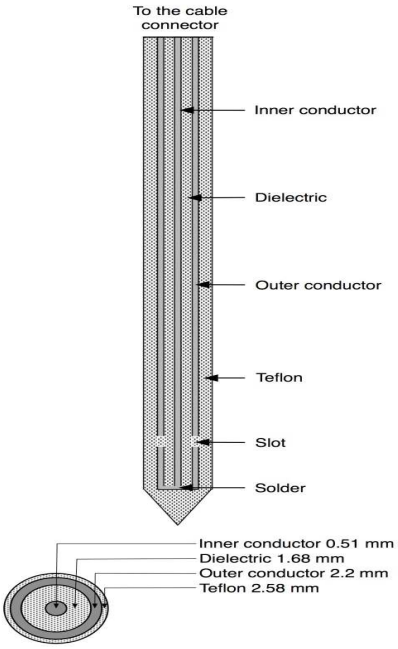


Figure 1: Design of the Antenna

Table 2: Properties of Material

PROPERTIES	CONDUCTOR(Dielectric)	CATHETER
Relative permittivity	2.035	2.609

NUMERICAL SIMULATION

As described above, the liver model was modelled from the set of MRI images. Then, the microwave antenna was modelled and then inserted into the tumour tissue. The destructive area of the tissue was finally expected to be identified. The microwave antenna was kept in the frequency of 2.4GHz. The heat, which is generated due to the electric-field in the waves was analysed by using COMSOL Multiphysics. Modules selected for the simulation were RF module and the bio heat. FEM meshing refinement was done by tetrahedral mesh shape. The physics and all the boundary condition were assigned to the domains and are shown in the above table. The simulation was performed on the laptop with the CPU Core-i7 2.5 GHz, under 64 bits Microsoft windows 8.1 and 8GB of RAM. The model was generated by using the axial symmetry domain, 2D model is produced and used in the initial design of antenna and in main approximation of

temperature and electromagnetic parameters, and also the temperature profile follows the heat source distribution. The FEM analysis (Finite Element Analysis) involves separating a complex domain into the small elements for partial different equation, evaluated at nodes or edges.

REAL IMAGE GEOMETRY MODEL

In the numerical analysis, correction of model is important in the simulation. In this paper, a set of real image from the MRI sliced was introduced to enhance the liver model design. The actual images help in working on actual volume and size of tumour for better result. Motive is to find out the time in which, required temperature can be obtained, which is possible only with the actual volume and size of the tumour. MRI images in axial view, sagittal view and coronal view were imported and rebuild to obtain liver model with .stl format. This was done with the help of mimics software and through manual segmentation. Later, the model was imported into COMSOL multiphysics for the simulation. Other Physics softwares used in the process were MIMICS and MAGICS by the materialized, these were used for the generation and the refinement of the 3D model, which then was imported into the COMSOL MULTIPHYSICS and then was simulated for the different time durations.

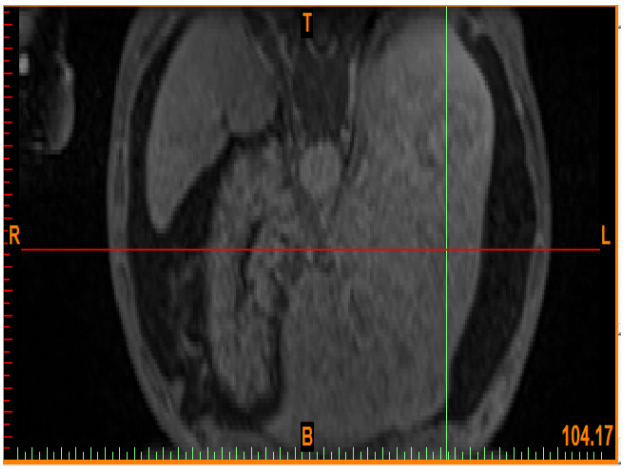


Figure 2: Axial View

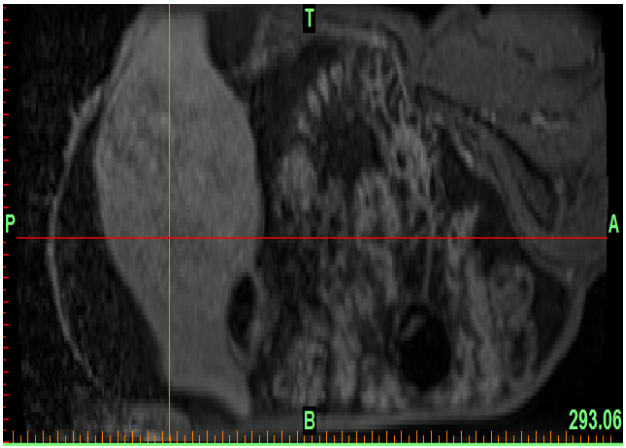


Figure 3: Sagittal View

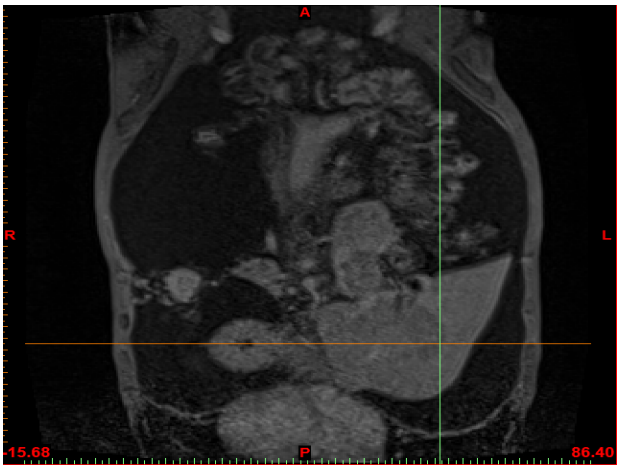


Figure 4: Coronal View

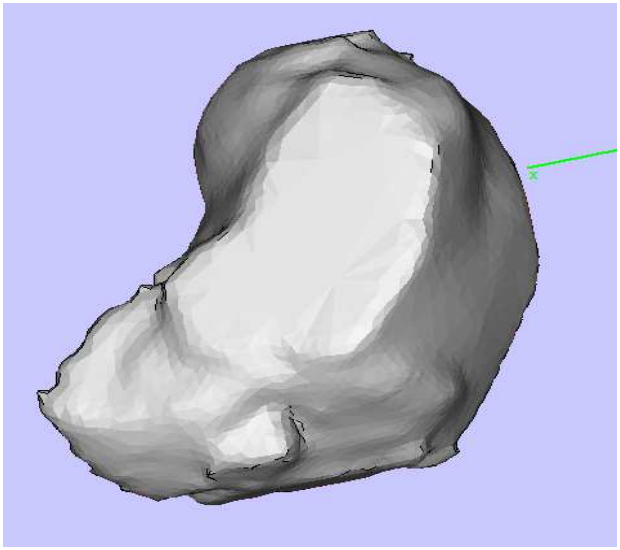


Figure 5: 3D CAD Model

COMSOL MODEL

In FEM analysis, a correction of model geometry plays an important role in simulation. In this study, a set of real image from MRI sliced was introduced to liver model. MRI image in sagittal view, axial view and coronal view were imported and refined to obtain a liver model in CAD file model with stl format. This implementation was succeeded by using general mimic type program and segmentation. Volume of liver model is 927800 mm^3, having a surface area of 58570 mm^2. Total number of domains are two, containing 120 boundaries and 433 edges. Volume of tumour is 4861 mm^3 and surface area is 1466 mm^2.

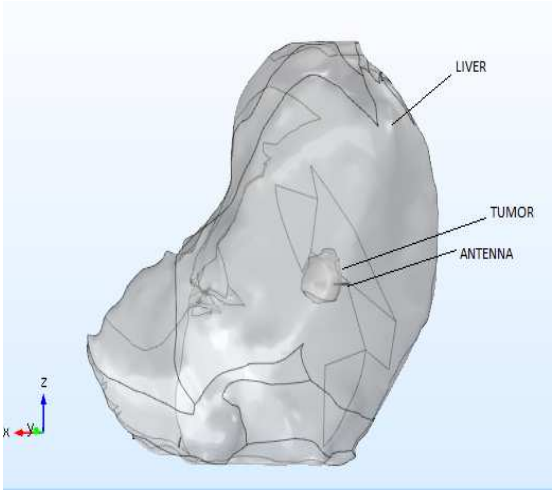


Figure 6: 3d Model of Cancerous Liver

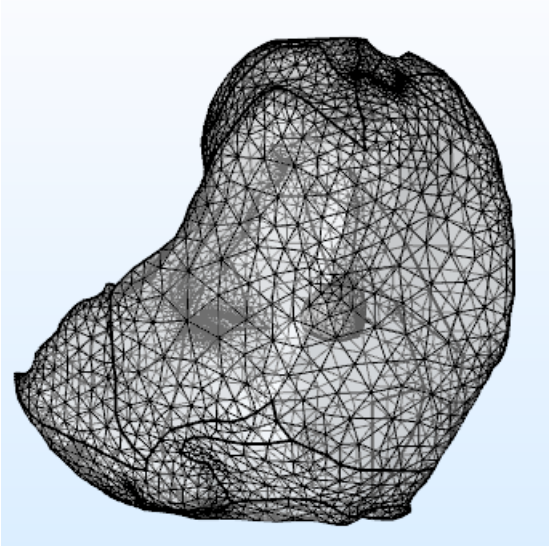


Figure 7: Mesh Refinement Representation

DOMAIN AND BOUNDARY EQUATIONS

Electromagnetics

Electromagnetic wave in the coaxial table is categorized by transverse electromagnetic fields. Time harmonic fields with the amplitudes contain the phase information and the appropriate equation is:

$$E_O = e_r \frac{C}{r} e^{j(\omega t - kz)} \quad (6)$$

$$H_O = e_\varphi \frac{C}{Z} e^{j(\omega t - kz)} \quad (7)$$

$$p_{av} = \int_{ri}^{ro} R\left(\frac{1}{2} E * H\right) 2\pi r dr = e_z \pi \frac{C\hat{}2}{Z} \ln\left(\frac{ro}{ri}\right) \quad (8)$$

Where,

z = Direction of the propagation.

r,φ and z = Cylindrical coordinates on the axis of the coaxial cable.

r i and *r o* = Dielectric inner and outer radius

p_{av} = Averaged power flow in the cable.

Z = Wave impedance in the dielectric of the cable.

ω = Angular frequency.

The propagation constant k, which relates to the wavelength in the medium, λ as:

$$k = \frac{2\pi}{\lambda} \quad (9)$$

Magnetic field in the azimuthal direction in the tissue and electric field has a finite axial-component. Antenna can be modelled using an axi-symmetric formulation. The wave equation now become scalar in Hr:

$$\nabla * ((\varepsilon_r - \frac{j\sigma}{\omega\varepsilon_o})^{-1}\nabla * Hr) - \mu_r k_o^2 Hr = 0 \quad (10)$$

The boundary conditions for the metal surfaces are:

$$N*E = 0 \quad (11)$$

Port condition with a power level set to 5W is used, which is basically a first order low reflecting boundary condition with an input field Hr:

$$n * \sqrt{\varepsilon}E - \sqrt{\mu}Hr = -2\sqrt{\mu}Hr \quad (12)$$

Where,

$$Hr = \frac{\sqrt{\frac{PavZ}{\pi r \ln(ro/ri)}}}{r} \quad (13)$$

HEAT TRANSFER

The bioheat equation describes the time dependent heat-transfer problem as:

$$\rho C_p \frac{dT}{dt} + \nabla*(-k\nabla T) = \rho_B C_B \omega_B (T_B - T) + Qo + Qe \quad (14)$$

where,

k = Tissue thermal conductivity (W/m*k)

ρ_B = Blood density (kg/m^3)

ω_B= Blood perfusion rate (1/s)

T_B= Arterial blood temperature (K)

Qo= Metabolism heat source (W/m^3)

Qe = External heat source (W/m^3)

C_B = Blood specific heat capacity

The initial temperature T_b is applied for all the domains. The heat source because of the metabolism is ignored in

this model.

The external heat source = heat generated by the electromagnetic field:

$$Qe = \tfrac{1}{2} R[(\sigma - j\omega\varepsilon)E^*E] \quad (15)$$

Degree of tissue injury α during the process is based on the Arrhenius equation:

$$\frac{d\alpha}{dt} = a^*\exp(-\frac{dE}{RT}) \quad (16)$$

Where, a is the frequency factor (1/s).

Table 3: Physical Properties of Liver

PROPERTIES	VALUE
Heat Capacity	3540[J/kg*K]
Density	1079[kg/m^3]
Thermal Conductivity	0.52[W/m*K]
Frequency factor	7.39*10^{39}[1/s]
Activation energy	2.5*10^5[J/mol]

Table 4: Physical Properties of Tumor

PROPERTIES	VALUE
Heat Capacity	3540[J/kg*K]
Density	1079[[kg/m^3]
Thermal Conductivity	0.52[W/m*K]
Frequency factor	9.4*10^{104}[1/s]
Activation energy	660000[J/mol]

Table 5: Parameters of Blood

PARAMETERS	VALUE
Density of blood	1000[kg/m^3]
Heat capacity	4180[J/kg*K]
Blood perfusion rate	0.0064[1/s]
Arterial blood temperature	37°C
Initial and boundary temperature	37°C

SPECIFIC ABSORPTION RATE DISTRIBUTION (SAR)

SAR can be defined as the energy absorbed by living tissue, when body is exposed to electromagnetic field, and radio-frequency range can be measured by the specific absorption rate. This indicates absorption power per mass of living tissue or watts per kilogram (W/kg). The heating ability of microwave antenna is studied with the help of SAR distribution. Heat generated by an electric field in living tissue is given by:

$$SAR = \frac{\sigma * E\hat{}2}{\rho}$$

where,

ρ = Density of tissue (kg/m^3)

σ = Conductivity of tissue (S/m)

E = Electric field (V/m)

Heat generated by antenna, SAR can be applied as external heat source in bio heat. Therefore, bio-heat equation can be written as:

$$\rho * C_P \frac{dT}{dt} + \nabla (-k\nabla T) = h*(T_b - T) + \rho * SAR$$

RESULTS

Hyperthermia is a therapy, in which the temperature of the cancerous tissue is elevated to 41°C - 45°C in order to kill the cells that are infected. In this paper, the MRI image of the liver cancer is taken and then converted into the 3d model, with the suitable cad software. The figure 8,9,10,11 shows the temperature distribution inside the liver tumour, when the power supply to the antenna is 1w to 4w. The frequency at which the electromagnetic waves are inserted inside the living tissue is 2.45GHz. The results shown in this figure were obtained, when the cancerous tissue was heated for the duration of the 10 minutes. As it can be seen that, as the power supply of the antenna is increased, the temperature inside the cancerous tumour also increased. The time that it takes to obtain the temperature range 41°C - 45°C ,which is required for the killing of the cells in hyperthermia, can be seen that it differs at each power change, more the power supply inside the antenna, less time it will take to attain that temperature. Figure 12,13 shows the temperature profile at the three different points in the surface of the tumour for the duration of the 10 and 20 minutes, respectively. The curve with the highest peak is the point near the antenna. The maximum temperature is at the tip of the antenna, and as we move away from the antenna, the temperature of the tissue keeps on decreasing until it reaches the normal body temperature. The results are computed at the liver model, whose volume is 927800 mm^3 and the surface area of the liver model is 58570 mm^2 ,whereas, the volume of the tumour region is 4861 mm^3 and the surface area of the tumour region is taken as 1466 mm^2. The power required and the temperature produced inside the tumour also depends upon the area of the tumour region. The intensity of power of the antenna is kept between 1W to 4W, and the maximum temperature attainted by the liverB model is between 39^{o}C to 46^{o}C , and the time duration under which the temperature increase was studied as 10, 20, 30 minutes, respectively. The material used for the antenna is dielectric and catheter.

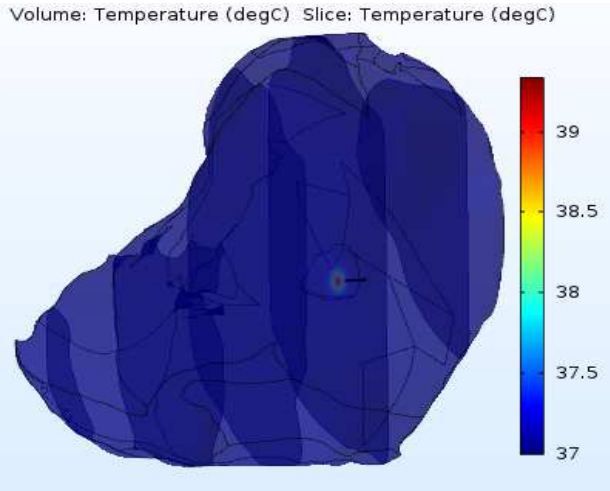


Figure 8: Temperature Distribution at Power Supply 1w

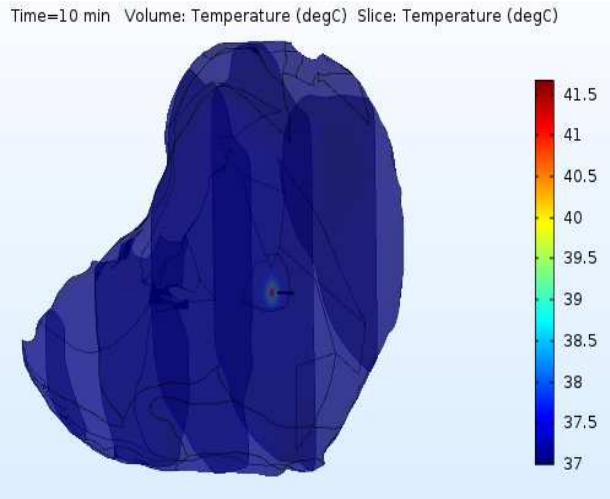


Figure 9: Temperature Distribution at Power Supply 2w

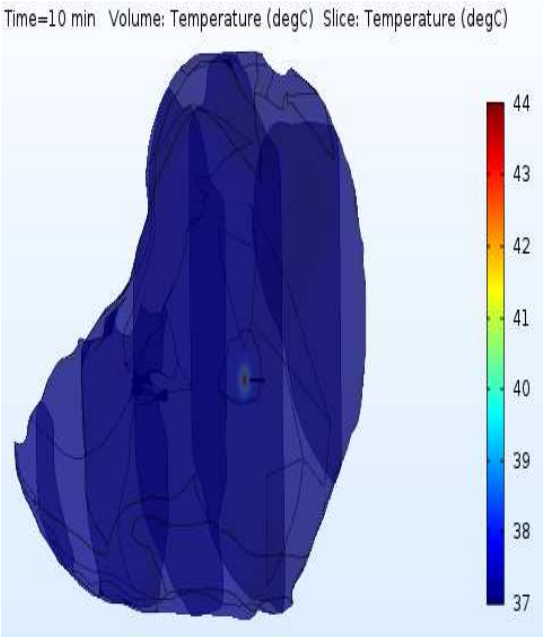


Figure 10: Temperature Distribution at Power Supply 3w

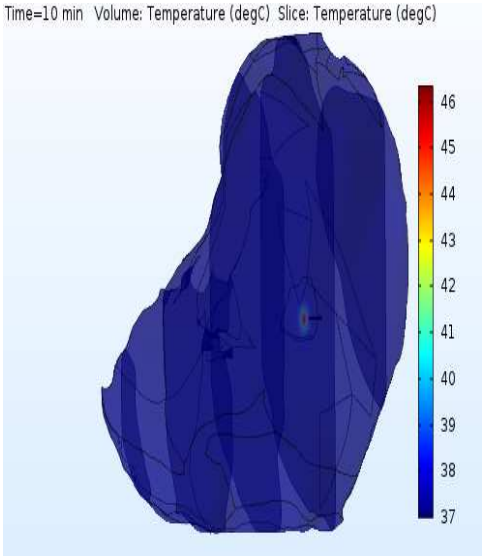


Figure 11: Temperature Distribution at Power Supply 4w

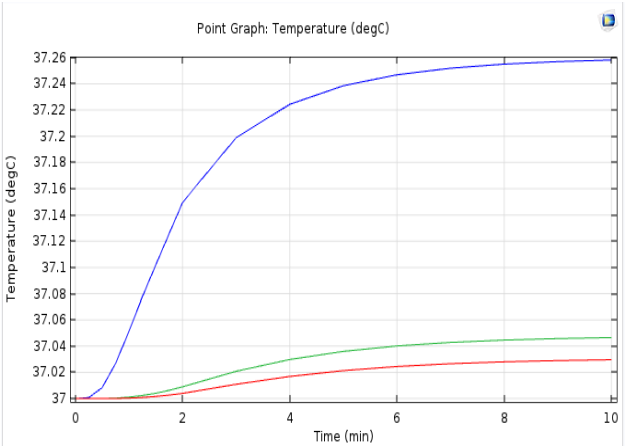


Figure 12: Temperature Distribution in the Surface of Tumorat Three different Points During the Duration of 10 Minutes

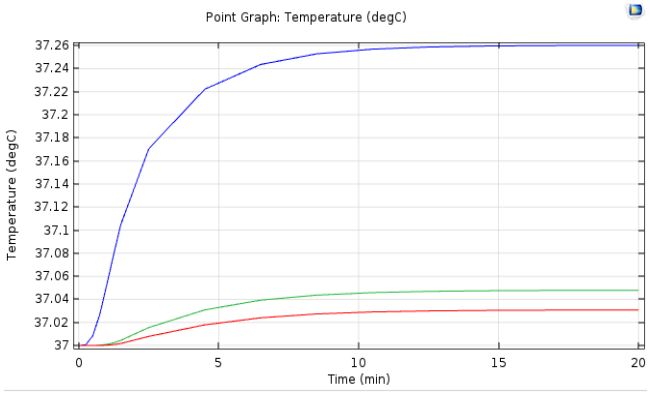


Figure 13: Temperature Distribution in the Surface of Tumor at Three different Points During the Duration of 20 Minutes

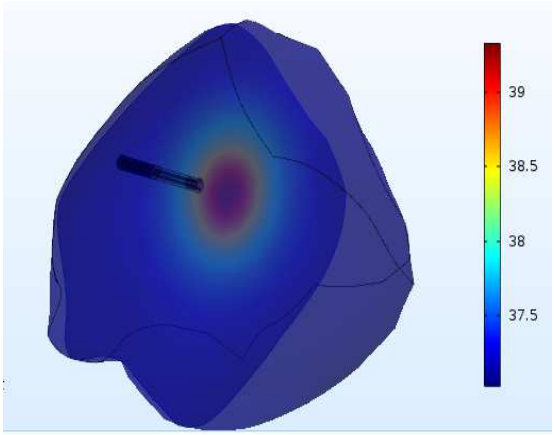


Figure 14: Temperature Distribution Inside the of Tumour

Table 6 shows the interaction between the power and the temperature at the time duration of 10, 20 & 30 minutes. From the table below, one could make the observation that the rise in the temperature inside the tissue, when exposed to the electromagnetic wave increased only up to 10 minutes, after that it become constant and the same can be seen with all the other power supplies.

Table 6

POWER (W)	TEMPERATURE (max.)		
	10 min	20 min	30 min
1W	39°C	39°C	39°C
2W	41.5°C	41.5°C	41.5°C
3W	44°C	44°C	44°C
4W	46°C	46°C	46°C
5W	48°C	48°C	48°C

The figure 15 shows the relationship between the temperature profile and the power supply. The above graph is plotted for the point which is 5mm away from the tip of the antenna. The rise in temperature can be seen at every power supply. The time duration at this, the cancerous cell was heated was 10 minutes. The table 7 shows the value of temperature at the point which is 5mm from antenna for the all 10 minutes for the power supply of 1w, 2w, 3w & 4w, respectively.

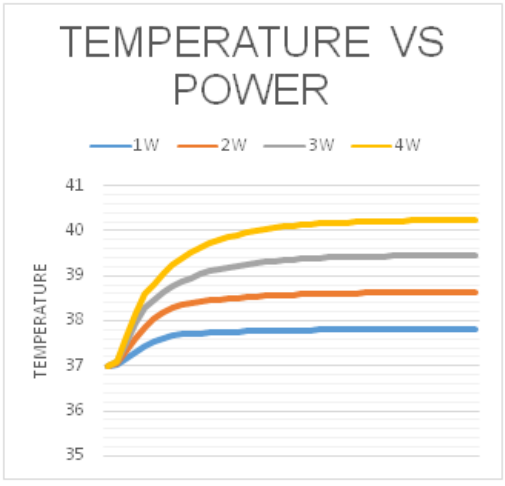


Figure 15: Temperature vs Power

Table 7

Time (m)	Temperature (°C)			
	1 W	2W	3 W	4 W
0	37.00	37.00	37.00	37.00
1	37.70	38.35	38.85	39.40
2	37.74	38.48	39.12	39.79
3	37.77	38.53	39.27	39.90
4	37.78	39.57	39.29	40.00
5	37.79	38.58	39.34	40.11
6	37.80	38.59	39.38	40.17
7	37.81	38.60	39.41	40.20
8	37.85	38.62	39.42	40.22
9	37.87	38.62	39.43	40.24
10	37.90	38.70	39.45	40.24

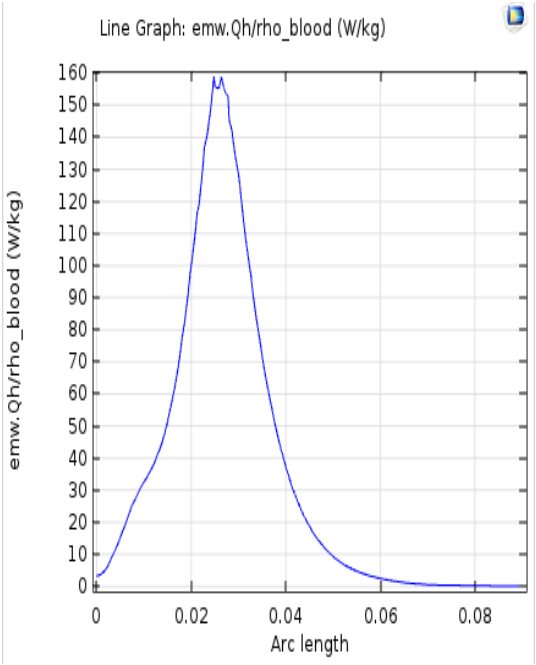


Figure 16: SAR Distribution Plot at the Surface of the Tumor, the Antenna Inserted Inside the Tumor is at A Frequency of 2.4ghz

CONCLUSIONS AND DISCUSSIONS

From the temperature profile distribution, it can be seen that focusing point of the electromagnetic field near the tip of antenna, is responsible for the hot spot in the temperature distribution in the tissue. The material used for the antenna is dielectric and catheter. The frequency at which the power is supplied to the antenna is taken as 2.45GHz. Foster et. al. recommended uniform semi-infinite homogeneous and uniform homogeneous sphere planes of thetissue. SAR calculation and the resulting temperature rise was projected by the finite element solution of the bio-heat equation. Our study will continue with the investigation of non-homogenous heating.

REFRENCES

1. *Sterzer, F.(2002),"Microwave medical devices. IEEE Microwave Magazine", 3(1).*

2. *Seegenschmiedt, Fessenden, and Vernon, C.C (1995),"Thermoradiootherapy and thermos-chemotherapy". Springer-Verlag, (1995)*
3. *Seki, T.Wakabayshi, M. Nakagawa, T. Itoh, T.; Kunieda, Sato, M. Uchiyama, S. and Inoue, K. (1994). Ultrasonically guided percutaneously microwave coagulation therapy for small carcinoma. Cancer, 74(3).*
4. *Ito, K. Ueno, K.Hyado, M.; and Kassi H. (1989). "Interstitial applicator composed of coaxial ring slot for microwave hyperthermia. Proceedings of International symposium on antenna and propagation".*
5. *Habash, R.W.Y.andAlhafid, H.T (2006). "Key developments in therapeutic appliactions of RF/microwaves. International journal of scientific research,16".*
6. *Yang, D.;Converse, M.C.Mahvi, D.M. and Webster,J.G. (2007). "Expanding the bioheat equation to include tissue water evaporation during heating, IEEE Transactions on Biomedical Engineering,54(8)".*
7. *Haemmerich, D. dos Santos, I. Schutt, D.J.; Webster, J.G and Mahvi, D.M. (2006). "In Vitro measurement of tempretaure-dependent specific heat of liver tissue. Medical Engineering and Physics,28(2)".*
8. *COMSOL Multiphysics, 3.5. (2010) "User's Guide. Electromagnetic Module, Heat Transfer Module"*
9. *Khalatbari S.,Sardari D.,Mirzaee A., and Sadafi H., "Calculated SAR in two model of the human head exposed to mobile phone radiation at 900 and 1800MHz,".*
10. *W.L Nyborg.(1988) "Solution of the bio-heat transfer equation".*
11. *Bert Hildebrandt, Peter Wust, Olaf Ahlers, Annette Dieing, Geetha Sreenivasa, Thoralf Kerner, Roland Felix, Hanno Riess, (2002)"The cellulr and molecular basis of hyperthermia", Crit. Rev.Oncol./Hematol.33-56.*
12. *Robert C. Hansen, (2009), "Phased Array Antennas", second ed., John Wiley & Sons Inc.*
13. *Piotr gas, "Study on interstitial microwave hyperthermia with the mult-slot coaxial antenna".*